

Phytotoxicology Investigation in the Vicinity of Essar Steel Algoma Inc. Sault Ste. Marie - 2009

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Background:

Essar Steel Algoma Inc. (formerly Algoma Steel Incorporated) is an integrated primary iron and steel producer located on the St. Mary's River in Sault Ste. Marie, Ontario. Integrated mills produce steel in blast furnaces where iron ore is mixed with coke and burned under controlled conditions so that carbon monoxide is produced. The carbon monoxide chemically reduces the iron ore, consisting primarily of iron oxides, to metallic iron. Limestone added to the furnace provides an additional source of carbon monoxide as well as acting as a flux to fuse with silicates in the ore. The resulting calcium silicate floats to the top of the molten iron and is drawn off as slag.

Coke is a critical material in steel making. It is produced by heating coal to high temperatures and distilling off the volatile components of the coal. The remaining material consists primarily of carbon and is known as coke. Coke provides the high heating value to smelt the iron ore and is also the source of carbon in steel.

Integrated mills produce coke in coke ovens. The ovens consist of narrow vertical chambers known as 'batteries'. The heat to distill the coal is generated by burning gases in spaces between adjoining chambers. Volatile compounds released as the coal is distilled are condensed to produce coal tar while the non-condensed gases are recovered and burned to distill fresh charges of coal.

Polycyclic Aromatic Hydrocarbons:

During coke production there are inevitable emissions of volatilized coal tar or of coal gas to the atmosphere. Major constituents of coke oven emissions are a class of organic compounds known as polycyclic aromatic hydrocarbons (PAHs). PAHs consist of three or more fused aromatic rings. Some consist only of carbon and hydrogen atoms while others have other atoms that replace carbon in the benzene ring or functional groups that replace the hydrogen atoms. Consequently, it is possible to have a great diversity of PAHs. It should be noted that PAHs are not necessarily constituents of coal but can be formed during the coal distillation process.

The boiling points of PAHs are usually high enough so that they do not persist in the atmosphere in vapour form, but will condense onto particulates acting as condensation nuclei. Consequently, the dispersion and deposition characteristics of PAHs is dependant on the behaviour of the particulate nuclei. Small particles will be transported greater distances than larger particles and can theoretically contain a higher mass to volume ratio of adsorbed PAHs. However, since the greater the dispersion distance, the greater the dilution, ambient air concentrations of PAHs, either in vapour or particulate form, are invariably higher near a point source.

The primary concern with PAHs is that some are considered probable human carcinogens. One of these, benzo(a)pyrene, has been the subject of considerable toxicological research and is the only PAH compound for which Ontario has an ambient air standard. This standard, which is 1.1 nanograms per cubic metre of outdoor ambient air per 24 hours, is

regularly exceeded at a MOE air monitoring station located near the Essar Steel Algoma complex.

Investigation Design:

At the request of the MOE Sudbury District Office, the Terrestrial Assessment Unit conducted an investigation to assess soil Pah concentrations in a residential neighbourhood adjacent to the Essar Steel Algoma complex in Sault Ste. Marie. The investigation was conducted on September 16 and 17, 2009. It followed an identical investigation conducted in 2005 and documented in Phyto-S5020-2005. Previous Ministry investigations, specifically those conducted in 1998 and 2003, concluded that the effects of PAH emissions from Essar Steel Algoma could only be detected in the residential neighbourhood immediately adjacent to the facility.

The Ministry's 2005 investigation consisted of surface soil sampling at 30 residential properties in the neighbourhood immediately adjacent to Essar Steel as well as sampling soil in depth increments at three of these properties. In 2009, the same 30 locations were sampled using the protocols followed in 2005. Three of these locations (different from those sampled in 2005) were also sampled in depth increments. These locations, however, were sampled in six increments of five centimetres each to a depth of 30 centimetres, while in 2005, four increments to 20 centimetres were sampled.

Figure 1 consists of an orthorectified image of the investigation area captured during an air photography survey in 2004. The surface soil sampling locations are designated with yellow squares. Dots within the squares identify locations where depth increment sampling occurred in 2005 and 2009

Sampling Procedures:

Prior to sampling at each location, all sampling equipment was washed with a high-phosphate detergent, rinsed with de-mineralized water, and then successively rinsed with acetone and hexane. Amber glass jars with Teflon™ lids were used to hold the samples. These containers were specially prepared for containing environmental samples destined for chemical analysis.

The sampling area for the surface soil samples consisted of the whole sodded portion of the yard, or an area about 10 metres by 10 metres if the yard was particularly large. Ten cores of soil to a depth of 2.5 centimetres were collected over a grid pattern with a soil coring device consisting of a hollow, two centimetre diameter, stainless steel tube fitted with a cutting tip. All cores taken from a sampling location were placed into a common jar.

The soil profile sampling utilized the same equipment however the corer was inserted to depth of at least 30 centimetres. A sliding hammer fitted to the corer was required to reach this depth. The extracted soil core was sectioned into the six increments of five centimetres each and placed into jars. Three cores were collected and each increment class was placed into a common jar.

All samples were forwarded to the MOE Laboratory Services Branch for determination of PAH concentrations by gas chromatography - mass spectrometry (GC-MS). The analytical

method was the same as was used in 2005. The analysis included spiking of the samples with deuterium-labelled PAH compounds and determining the proportion of the spikes recovered during the concentration determination. This recovery value was used to correct the apparent concentrations of the target PAH compounds. This methodology is more precise and expands the list of PAHs that are quantified by two for a total of 18.

Figure 1: Soil Sampling Locations - Essar Steel Algoma, Sault Ste. Marie - 2005 & 2009



Results:

Table 1 provides the concentrations of the 18 PAH compounds in the surface soil from the 30 locations collected during the 2009 investigation as well as from the same locations in 2005. Tables 2 and 3 contain PAH data for the soil collected in depth increments in 2005 and 2009. Concentrations are in nanograms per gram, also known as parts per billion, on a dry weight basis.

The tables also contain columns listing the concentrations from O. Reg. 153/04 Table 1 (Full Depth Background Site Condition Standards) and Table 3 (Full Depth Generic Site Condition Standards in a Non-Potable Ground Water Condition) as contained in the *Soil, Ground Water and Sediment Standards for Use Under Part XV.1 of the Environmental Protection Act*. The Appendix to this report contains information on the legislation governing standards for soil contaminants.

Data are highlighted in bold text if a concentration exceeds the background "Table 1" concentration. If concentrations are also high enough to exceed the health-based "Table 3" concentrations, the cells are shaded.

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Table 1: PAHs (ng/g dw) in Surface Soil (0-2.5 cm) near Essar Steel Algoma - 2005 & 2009

Site Year	21		22		23		24		25		26	
	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009
Naphthalene	460	480	280	300	230	300	180	270	300	350	240	280
Acenaphthylene	53	60	39	40	45	63	26	36	62	100	83	94
Acenaphthene	13	12	12	12	13	21	8	14	33	46	19	25
Fluorene	62	62	40	41	40	58	29	37	61	75	41	52
Phenanthrene	490	550	340	390	410	580	240	350	670	870	480	680
Anthracene	62	70	45	48	53	85	31	47	98	140	74	110
Fluoranthene	620	660	460	500	630	870	310	460	1,100	1,700	980	1,400
Pyrene	510	530	360	400	500	680	250	370	930	1,400	830	1,100
Benzo(a)anthracene	270	280	190	190	240	320	130	180	500	710	430	530
Chrysene	520	590	340	390	450	650	250	360	840	1,300	710	980
Benzo(b)fluoranthene	510	380	360	260	480	440	260	260	960	830	760	640
Benzo(k)fluoranthene	210	440	150	300	210	520	110	290	430	1,100	340	800
Benzo(e)pyrene	350	330	230	220	330	370	170	220	600	710	480	540
Benzo(a)pyrene	310	360	220	240	300	410	170	240	650	890	520	680
Perylene	84	82	59	57	95	98	51	57	190	390	160	170
Indeno(1,2,3-c,d)pyrene	350	370	250	260	330	420	280	290	910	830	690	630
Dibenz(a,h)anthracene	58	70	44	49	52	81	31	45	130	160	82	120
Benzo(g,h,i)perylene	280	370	200	260	260	400	160	250	570	800	470	580

Table 1 (cont'd): PAHs (ng/g dw) in Surface Soil (0-2.5 cm) near Essar Steel Algoma - 2005 & 2009

Site Year	27		28		29		30		31		32	
	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009
Naphthalene	140	200	200	210	120	130	170	230	210	170	320	290
Acenaphthylene	41	55	52	75	24	26	85	100	92	60	65	45
Acenaphthene	12	150	14	18	5	5.5	10	14	14	11	22	15
Fluorene	29	220	35	42	21	19	30	38	40	30	56	40
Phenanthrene	270	2,300	360	510	170	200	340	450	490	400	530	410
Anthracene	53	560	49	72	22	25	48	63	80	52	74	50
Fluoranthene	680	4,100	570	920	240	290	670	870	1,000	760	740	670
Pyrene	580	3,200	470	730	190	230	550	680	810	590	580	510
Benzo(a)anthracene	310	1,600	250	360	97	120	290	350	410	290	300	260
Chrysene	440	2,400	460	710	210	250	500	660	730	570	580	500
Benzo(b)fluoranthene	490	1,500	490	480	240	180	570	490	760	400	580	350
Benzo(k)fluoranthene	230	1,800	210	590	96	210	250	610	340	470	250	410
Benzo(e)pyrene	320	1,200	330	410	140	150	390	420	460	340	360	300
Benzo(a)pyrene	350	1,600	300	470	130	160	370	470	470	380	370	340
Perylene	120	550	88	110	42	38	120	130	150	90	110	78
Indeno(1,2,3-c,d)pyrene	470	1,300	450	470	220	180	560	500	690	410	520	340
Dibenz(a,h)anthracene	59	270	58	94	27	33	66	98	96	77	68	68
Benzo(g,h,i)perylene	260	1,200	270	440	130	170	320	470	400	370	310	330

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Table 1 (cont'd): PAHs (ng/g dw) in Surface Soil (0-2.5 cm) near Essar Steel Algoma - 2005 & 2009

Site Year	33		34		35		36		37		38	
	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009
Naphthalene	280	190	160	160	250	180	190	200	170	180	170	180
Acenaphthylene	39	27	25	22	74	34	69	50	66	53	59	81
Acenaphthene	10	7	4	8	15	10	12	10	15	16	7	16
Fluorene	32	26	21	25	40	28	34	28	33	33	21	43
Phenanthrene	330	260	200	250	410	290	390	310	410	430	260	500
Anthracene	40	30	30	34	63	36	57	42	56	56	39	64
Fluoranthene	440	340	350	410	650	420	640	540	890	890	540	920
Pyrene	340	260	270	310	510	320	520	420	720	710	440	750
Benzo(a)anthracene	170	130	140	150	260	160	280	220	340	330	230	390
Chrysene	360	280	250	310	550	370	560	470	590	640	410	650
Benzo(b)fluoranthene	350	190	270	210	540	250	550	320	680	480	490	530
Benzo(k)fluoranthene	150	210	110	240	230	270	240	360	310	560	210	620
Benzo(e)pyrene	230	170	170	170	350	210	330	260	380	370	300	460
Benzo(a)pyrene	220	170	170	190	330	230	330	280	440	430	310	540
Perylene	57	38	48	46	100	48	91	67	120	100	100	150
Indeno(1,2,3-c,d)pyrene	370	170	260	190	520	260	510	320	670	470	510	510
Dibenzo(a,h)anthracene	45	34	32	36	62	42	64	53	89	85	58	100
Benzo(g,h,i)perylene	210	170	140	190	300	220	290	280	360	450	270	450

Table 1 (cont'd): PAHs (ng/g dw) in Surface Soil (0-2.5 cm) near Essar Steel Algoma - 2005 & 2009

Site Year	39		40		41		42		43		44	
	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009
Naphthalene	110	320	210	100	450	550	420	440	250	340	260	360
Acenaphthylene	19	34	31	25	48	54	110	94	64	86	42	49
Acenaphthene	7	30	10	8	13	14	14	14	10	14	14	13
Fluorene	16	49	24	20	48	64	51	59	36	47	32	45
Phenanthrene	160	520	250	200	500	600	680	750	370	490	340	460
Anthracene	19	65	33	26	48	70	85	110	52	82	40	56
Fluoranthene	230	840	320	310	610	810	1,400	1,500	680	1000	510	640
Pyrene	180	620	250	240	500	630	1,400	1,400	550	810	420	460
Benzo(a)anthracene	87	300	130	120	240	320	700	710	310	460	200	250
Chrysene	170	600	280	220	540	650	1,100	1,200	510	740	430	500
Benzo(b)fluoranthene	190	420	300	170	500	430	1,200	740	540	560	430	350
Benzo(k)fluoranthene	82	460	130	180	240	490	550	920	250	640	220	380
Benzo(e)pyrene	120	340	210	150	290	410	660	740	300	480	260	330
Benzo(a)pyrene	120	390	180	170	300	400	780	910	330	560	280	320
Perylene	35	88	68	50	77	110	200	240	88	150	75	82
Indeno(1,2,3-c,d)pyrene	200	430	340	190	420	390	950	810	450	520	370	330
Dibenzo(a,h)anthracene	22	62	38	29	61	81	150	170	71	110	54	60
Benzo(g,h,i)perylene	110	350	200	150	300	370	640	680	270	450	250	300

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Table 1 (cont'd): PAHs (ng/g dw) in Surface Soil (0-2.5 cm) near Essar Steel Algoma - 2005 & 2009

Site Year	45		46		47		48		49		50	
	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009	2005	2009
Naphthalene	480	460	230	300	210	240	170	230	180	220	200	240
Acenaphthylene	57	58	110	150	47	47	42	48	20	22	41	50
Acenaphthene	14	12	16	14	55	13	11	12	8	8	10	13
Fluorene	44	51	45	63	86	39	31	36	26	32	34	40
Phenanthrene	480	520	580	710	1,200	450	290	370	240	260	370	400
Anthracene	46	61	80	110	150	76	39	54	29	33	59	57
Fluoranthene	610	750	1,300	1,500	2,800	1200	470	610	280	300	540	590
Pyrene	480	560	1,000	1,200	2,300	940	400	460	210	220	410	440
Benzo(a)anthracene	260	310	520	670	1,100	550	210	260	110	120	210	250
Chrysene	590	600	910	1,100	1,800	890	410	450	280	270	390	460
Benzo(b)fluoranthene	570	460	1,000	850	2,100	710	410	360	250	190	370	330
Benzo(k)fluoranthene	250	500	480	980	1,000	820	200	400	100	190	160	370
Benzo(e)pyrene	330	420	580	810	1,200	630	240	350	150	180	220	300
Benzo(a)pyrene	350	430	640	880	1,400	710	260	380	130	170	230	320
Perylene	89	120	180	260	420	210	66	100	29	43	55	89
Indeno(1,2,3-c,d)pyrene	560	510	880	810	1,700	790	400	390	200	180	330	320
Dibenzo(a,h)anthracene	69	71	120	150	220	130	45	68	32	34	43	65
Benzo(g,h,i)perylene	350	400	540	630	1,100	610	220	330	140	150	220	250

Table 1 (cont'd): PAHs (ng/g dw) in Surface Soil (0-2.5 cm) near Essar Steel Algoma - 2005 & 2009

Soil Standards (O. Reg. 153/04)	Table 1	Table 3
Naphthalene	90	40,000
Acenaphthylene	80	100,000
Acenaphthene	70	1,000,000
Fluorene	120	350,000
Phenanthrene	690	40,000
Anthracene	160	28,000
Fluoranthene	1,100	40,000
Pyrene	1,000	250,000
Benzo(a)anthracene	740	40,000
Chrysene	690	12,000
Benzo(b)fluoranthene	470	19,000
Benzo(k)fluoranthene	480	19,000
Benzo(e)pyrene	-	-
Benzo(a)pyrene	490	1,200
Perylene	-	-
Indeno(1,2,3-c,d)pyrene	380	12,000
Dibenzo(a,h)anthracene	160	1,200
Benzo(g,h,i)perylene	680	40,000

Table 2: PAHs (ng/g dw) in Soil Depth Increments near Essar Steel Algoma, SSM - 2005

Site Depth Increment (cm)	Site 21				Site 25			
	0-5	5-10	10-15	15-20	0-5	5-10	10-15	15-20
Naphthalene	450	410	200	170	300	380	180	110
Acenaphthylene	58	51	35	41	71	110	48	22
Acenaphthene	12	11	6.2	4.5	37	62	36	16
Fluorene	55	40	22	19	48	61	33	17
Phenanthrene	480	400	230	220	600	890	500	270
Anthracene	62	54	33	34	74	120	67	37
Fluoranthene	620	560	400	480	980	1,600	920	520
Pyrene	530	500	360	430	840	1,400	800	440
Benzo(a)anthracene	270	250	180	220	380	640	390	210
Chrysene	550	500	330	360	740	1,200	700	370
Benzo(b)fluoranthene	510	470	320	360	730	1,200	700	380
Benzo(k)fluoranthene	240	220	160	180	360	560	340	180
Benzo(e)pyrene	340	290	200	210	490	720	440	240
Benzo(a)pyrene	330	300	220	260	500	830	510	260
Perylene	99	93	69	72	140	250	130	67
Indeno(1,2,3-c,d)pyrene	510	380	260	320	590	1,000	680	440
Dibenzo(a,h)anthracene	56	52	37	43	96	160	100	48
Benzo(g,h,i)perylene	290	270	170	190	450	700	450	230

Site Depth Increment (cm)	Site 32				Table 1	Table 3
	0-5	5-10	10-15	15-20		
Naphthalene	300	260	210	230	90	40,000
Acenaphthylene	59	63	55	68	80	100,000
Acenaphthene	37	15	15	13	70	1,000,000
Fluorene	48	35	26	30	120	350,000
Phenanthrene	570	440	420	420	690	40,000
Anthracene	86	57	60	60	160	28,000
Fluoranthene	920	680	670	730	1,100	40,000
Pyrene	750	550	550	610	1,000	250,000
Benzo(a)anthracene	430	280	280	310	740	40,000
Chrysene	790	570	540	570	690	12,000
Benzo(b)fluoranthene	780	530	530	570	470	19,000
Benzo(k)fluoranthene	380	260	260	280	480	19,000
Benzo(e)pyrene	470	340	340	370	-	-
Benzo(a)pyrene	550	350	360	390	490	1,200
Perylene	170	110	100	97	-	-
Indeno(1,2,3-c,d)pyrene	890	590	610	660	380	12,000
Dibenzo(a,h)anthracene	100	67	81	83	160	1,200
Benzo(g,h,i)perylene	450	290	290	330	680	40,000

Table 3: PAHs (ng/g dw) in Soil Depth Increments near Essar Steel Algoma, SSM - 2009

Site Depth Increment (cm)	Site 42						Site 46					
	0-5	5-10	10-15	15-20	20-25	25-30	0-5	5-10	10-15	15-20	20-25	25-30
Naphthalene	420	440	440	530	480	620	270	160	240	620	460	460
Acenaphthylene	100	120	110	150	120	150	240	67	120	260	380	1,200
Acenaphthene	15	16	12	15	26	42	39	23	13	49	130	99
Fluorene	60	63	53	67	69	92	230	45	40	140	290	740
Phenanthrene	730	810	730	970	1,000	1,300	1,800	520	590	2,200	3,300	9,500
Anthracene	93	110	97	120	130	180	250	76	94	420	520	1,500
Fluoranthene	1,500	1,600	1,600	2,100	2,000	2,500	2,800	990	1,500	5,200	6,200	15,000
Pyrene	1,500	1,700	1,600	2,100	2,000	2,400	2,100	800	1,200	4,300	4,800	12,000
Benzo(a)anthracene	750	790	780	970	1,000	1,200	1,100	430	730	2,300	2,500	5,700
Chrysene	1,200	1,300	1,200	1,500	1,600	1,900	1,700	680	1,100	3,300	3,600	8,400
Benzo(b)fluoranthene	780	860	820	1,000	1,000	1,200	1,200	530	840	2,800	2,800	6,300
Benzo(k)fluoranthene	940	1,000	990	1,200	1,200	1,500	1,400	610	990	2,700	3,100	7,400
Benzo(e)pyrene	690	730	690	920	870	1,100	900	400	650	2,200	2,100	4,800
Benzo(a)pyrene	840	900	880	1,100	1,100	1,300	1,200	490	790	2,800	2,700	6,000
Perylene	200	210	200	260	240	310	280	120	200	700	1,100	1,600
Indeno(1,2,3-c,d)pyrene	840	910	790	1,200	1,100	1,200	1,300	540	860	3,000	3,000	6,900
Dibenzo(a,h)anthracene	150	170	160	210	190	240	230	96	160	370	400	700
Benzo(g,h,i)perylene	760	800	750	1,000	930	1,100	970	430	690	2,700	2,400	5,300

Site Depth Increment (cm)	Site 47						Table 1	Table 3
	0-5	5-10	10-15	15-20	20-25	25-30		
Naphthalene	250	240	140	110	98	110	90	40,000
Acenaphthylene	40	35	20	17	20	25	80	100,000
Acenaphthene	18	13	6.9	3.8	4.2	5	70	1,000,000
Fluorene	45	35	18	12	12	16	120	350,000
Phenanthrene	460	380	230	150	160	230	690	40,000
Anthracene	69	56	33	19	18	37	160	28,000
Fluoranthene	950	810	560	280	300	620	1,100	40,000
Pyrene	730	650	440	230	250	490	1,000	250,000
Benzo(a)anthracene	390	370	250	120	130	240	740	40,000
Chrysene	670	650	420	200	220	370	690	12,000
Benzo(b)fluoranthene	550	530	360	170	150	270	470	19,000
Benzo(k)fluoranthene	600	580	390	180	180	310	480	19,000
Benzo(e)pyrene	490	450	310	140	150	240	-	-
Benzo(a)pyrene	500	480	310	140	150	260	490	1,200
Perylene	170	150	99	42	45	72	-	-
Indeno(1,2,3-c,d)pyrene	530	520	350	160	160	260	380	12,000
Dibenzo(a,h)anthracene	97	96	63	29	27	47	160	1,200
Benzo(g,h,i)perylene	410	400	270	120	110	200	680	40,000

Discussion:

Since the protocols for sampling surface soil (0-2.5 cm) in 2009 were identical to those employed in 2005, as was the PAH analytical method, the two data sets are highly amenable for comparison. Since there were 18 PAHs determined at 30 locations on two occasions, a simplification of the data is required. This was accomplished by adding the concentrations for all 18 PAHs in each sample and calculating the difference between the totals. The difference was calculated by subtracting the 2005 sum from the 2009 sum and dividing by the average of the 2005 and 2009 sums [$(2009-2005) / (2005+2009)/2$], and expressing the result as a percent difference. Table 3 contains the results of the calculations.

Table 3: Comparison of 2005 & 2009 Soil PAH Concentrations

Site	2005	2009	% Difference
21	5,212	5,696	8.9
22	3,619	3,957	8.9
23	4,668	6,366	31
24	2,686	3,776	34
25	9,034	12,401	31
26	7,389	9,411	24
27	4,854	24,205	133
28	4,656	6,711	36
29	2,124	2,417	13
30	5,339	6,643	22
31	7,242	5,470	-28
32	5,835	5,006	-15
33	3,673	2,702	-31
34	2,650	2,951	11
35	5,254	3,378	-44
36	5,157	4,230	-20
37	6,339	6,283	-1.0
38	4,424	6,954	45
39	1,877	5,918	104
40	3,004	2,358	-24
41	5,185	6,443	22
42	11,090	11,487	3.5
43	5,131	7,539	38
44	4,227	4,985	17
45	5,629	6,293	11
46	9,211	11,187	19
47	18,888	9,055	-70
48	3,914	4,908	23
49	2,414	2,622	8.3
50	3,892	4,584	16

The agreement between PAH concentrations in soil samples collected and analysed in 2005 and in 2009 is excellent. The differences between 27 of the 30 samples are less than 50%. Given the degree of heterogeneity typically encountered in environmental sampling, it is safe to

conclude that there has not been a discernable change in PAH concentrations between 2005 and 2009 at 27 of the sampling locations. This is reinforced by the observation that there is no overwhelming direction in the change. The summed PAH concentrations were higher at 22 locations in 2009 and lower at eight.

The three remaining locations, Sites 27, 39 and 47, are distinguished by large differences between 2005 and 2009. In 2009, PAH concentrations were higher at two of these locations and lower in one. One of the sites was a municipal park while the other two were yards of residential properties.

The reason for the large differences in reported PAH concentrations between 2005 and 2009 at these three sites is not readily apparent. It was possible to view the sampling sites using the Street View feature of Google Earth. Neither field notes or memory refreshed by viewing the sites provided any explanation for the unique observations. Future investigations with intensive sampling could provide an explanation.

There are now two sites where concentrations of benzo(a)pyrene exceed the effects-based Table 3 standard of 1,200 nanograms per gram. This standard was exceeded at Site 47 in 2005 and at Site 27 in 2009.

The second part of the 2009 investigation expanded on the sampling of soil at depth initiated in 2005. In 2005, soil at Sites 21, 25 and 32 was sampled in five centimetre increments to a depth of 20 centimetres. In 2009, soil at Sites 42, 46 and 47 was sampled in five centimetre increments to a depth of 30 centimetres.

In 2005, soil sampling by depth increments revealed elevated PAH concentrations down to 20 centimetres, the deepest point sampled. Also, the highest concentrations tended to be present closer to the surface, consistent with atmospheric deposition. It was suggested that the coarse soil of the neighbourhood permitted the downward migration of fine PAH-containing particulates. This prevented higher accumulations of PAHs in the surface soil.

In 2009, three different sites were sampled by depth increments, but to a depth of 30 centimetres. One of these, Site 47, exhibited a PAH distribution similar to what was observed at the three 2005 sites, however, the deepest (25-30 cm) increment had higher PAH concentrations than increments immediately above it. At the other 2009 sites, Sites 42 and particularly Site 45, this PAH distribution is clear. At these two sites, the PAH concentrations are highest in the deepest increments. In the deepest increments at Site 47, the benzo(a)pyrene concentrations exceed the health-based Table 3 standards.

The reason for this unexpected distribution is not apparent. A possible explanation is the placement of uncontaminated soil over a contaminated layer followed by ongoing deposition contaminating the new material while the now buried layer remains static. Alternatively, downward migration of PAH-containing particulates through the coarse soil ceases, accumulating in the sub-surface. Neither of these or possible other explanations can be evaluated with the data available.

Conclusions:

In 2009, the PAH concentrations of surface soil samples collected from the residential neighbourhood immediately adjacent to Essar Steel Algoma in Sault Ste. Marie were in excellent agreement at 27 of the 30 locations sampled in comparison to data collected in 2005. The large differences found at three of the locations remains unresolved.

All 30 locations exceed one or more background-based Table 1 standards (*O. Reg. 153/04*) for PAHs, an indication that the surface soil has been contaminated by a nearby source. However, the surface soil at only two locations exceeds the effects-based Table 3 standard (*O. Reg. 153/04*) for benzo(a)pyrene.

Soil sampling in depth increments at three new locations revealed interesting distribution patterns of PAH in the depth profile. Higher concentrations of PAHs in surface soil were observed, consistent with the pattern where deposition from the atmosphere is the source of a contaminant. However, some very high concentrations were also observed in the sub-surface (below 0-5cm). Explanations for this phenomenon are not possible without more sampling/investigation.

APPENDIX A

Ontario Regulation 153/04 Soil, Ground Water, and Sediment Standards

The Ministry's soil, ground water, and sediment standards are for use under *Part XV.I* of the *Environmental Protection Act* and are referred to in the *Record of Site Condition Ontario Regulation 153/04*. In 1996 the Ministry published the *Guideline for Use at Contaminated Sites in Ontario*, which provided industrial property owners and their consultants with guidance in identifying and cleaning up contaminated soil on their property. As of October 1, 2004 the site assessment and remediation of properties for which a Record of Site Condition is filed will need to conform to the requirements set out in *O. Reg 153/04*.

The standards set out in *O. Reg 153/04* were developed from published U.S. EPA and Ontario environmental data bases. Currently there are criteria for about 25 inorganic elements and about 90 organic compounds. Criteria were developed only if there were sufficient, defendable, effects-based data on the potential to cause an adverse effect to human health or the natural environment. In setting the *O. Reg 153/04* standards, the Ministry reviewed the international literature and Ontario environmental data and determined the lowest concentration that may cause an adverse effect to the natural environment and the lowest concentration that may have an adverse human health effect and set the standard at whichever value was lower. By setting the standard to protect the most sensitive environmental receptor all other biological receptors, both human and the natural environment, should be protected by default. In cases where the criteria to protect human health or the natural environment are lower than natural background levels, then the *O. Reg 153/04* standard is set at background. The development of these standards is a continuous program, and criteria for more elements and compounds will be developed as additional environmental data become available. Similarly, new information could result in modifications to the existing standards.

O. Reg. 153/04 standards are not action levels, in that an exceedence does not automatically mean that a clean-up must be conducted. The criteria were prepared to help industrial property owners clean-up contamination on their property when the land is intended to be sold, the zoning changed, and/or the property redeveloped to a more sensitive land-use. For example, the owner of an industrial property that plans to sell the land to a developer to build residential housing must meet the criteria set out in *O. Reg. 153/04* in order to obtain a Record of Site Condition, which is an acknowledgement by the Ministry that they have met Ministry environmental standards. In this way previously-contaminated industrial land can be safely re-developed for residential or parkland use without concern for adverse environmental or human health effects. In addition, most municipalities insist that contaminated land is cleaned up according to *O. Reg 153/04* before they will approve a zoning change, therefore industrial property owners and developers are obliged to comply with the Regulation.

O. Reg. 153/04 contains a series of Tables (1 through 6), each having criteria for soil, sediment, and ground water for various land-use categories (eg, agricultural, residential, industrial). *Table 1* criteria reflect the upper range of background concentrations in Ontario. An exceedence of *Table 1* indicates the likely presence of a contaminant source. *Tables 2 through 5* criteria are effects-based and relate to potable or non-potable ground water conditions. The criteria in

Tables 2 through 5 take into consideration the potential for adverse effects from exposure to contaminated media through ingestion and direct contact, through contaminant transfer from soil to indoor air, from ground water or surface water through release of volatile gases, from leaching of contaminants in soil to ground water, and from ground water discharge to surface water. However, the criteria **may not** ensure that corrosive, explosive, or unstable soil conditions will be eliminated. Table 6 is used to determine if the property qualifies as a “shallow soil” property, which places additional restrictions on the site under Section 41 of *O. Reg 153/04*.

Although written specifically to assist industrial landowners in the sale and redevelopment of their own contaminated site, the environmental standards in *O. Reg. 153/04* are becoming used more widely to interpret soil, sediment, and ground water quality at the community or even the landscape scale. When used in this manner, an exceedence of the *O. Reg 153/04* criteria do not imply that remediation is required, rather it suggests that additional studies are warranted. These additional studies may involve more environmental sampling, an ecological or a human health risk assessment, or even a health study. Decisions on the need to undertake any additional studies when the criteria in *O. Reg. 153/04* are exceeded are made on a site by site basis and are usually contingent on the contaminants having the demonstrated likelihood to cause an adverse effect to the natural environment or human health.

Because of society’s long industrial history and our practice of living close to our work place the soil in many communities in Ontario may be contaminated above the effects-based criteria in *O. Reg 153/04*. In practice, remediation of contaminated soil on privately-owned residential property and public green spaces has only been conducted in communities when the potential for adverse health effects has been demonstrated.

For more information on the rationale for the Ministry’s soil, sediment, and ground water criteria in *O. Reg 153/04* please refer to the *Rationale for the Development and Application of Generic Soil, Ground Water and Sediment Criteria for Use at Contaminated Sites in Ontario (December 1996)*.